# Proof-of-concept pilot study of the PET module for the 1 mm resolution human brain PET

Goals:

- Separate 1.5mm LYSO pixels in a stack of 2-3 pixellated LYSO arrays to provide Depth-of-Interaction (DOI) information, using Silicon Photomultiplier (SiPM) array
- Achieve good (better than 15% FWHM @511 keV) and uniform energy resolution across detector surface
- Consider cooling if necessary to achieve the above goals

# Proof-of-concept of the PET module for the sub-mm resolution human brain PET

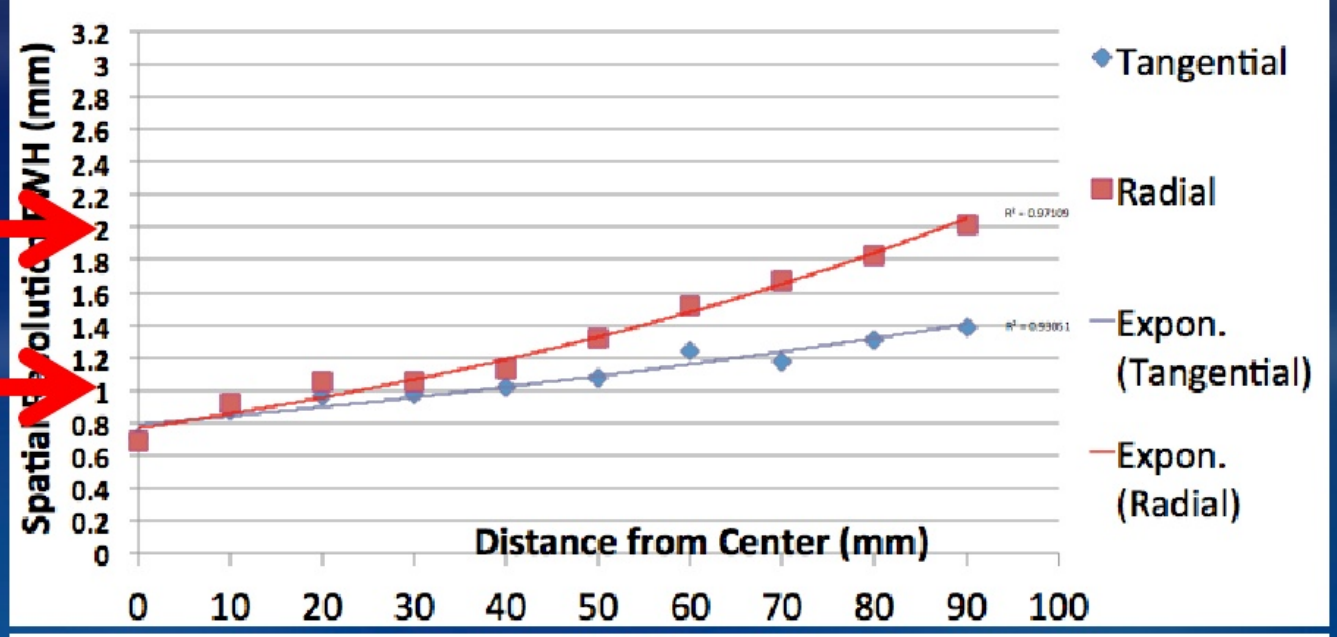
Rationale for the resolution goals:

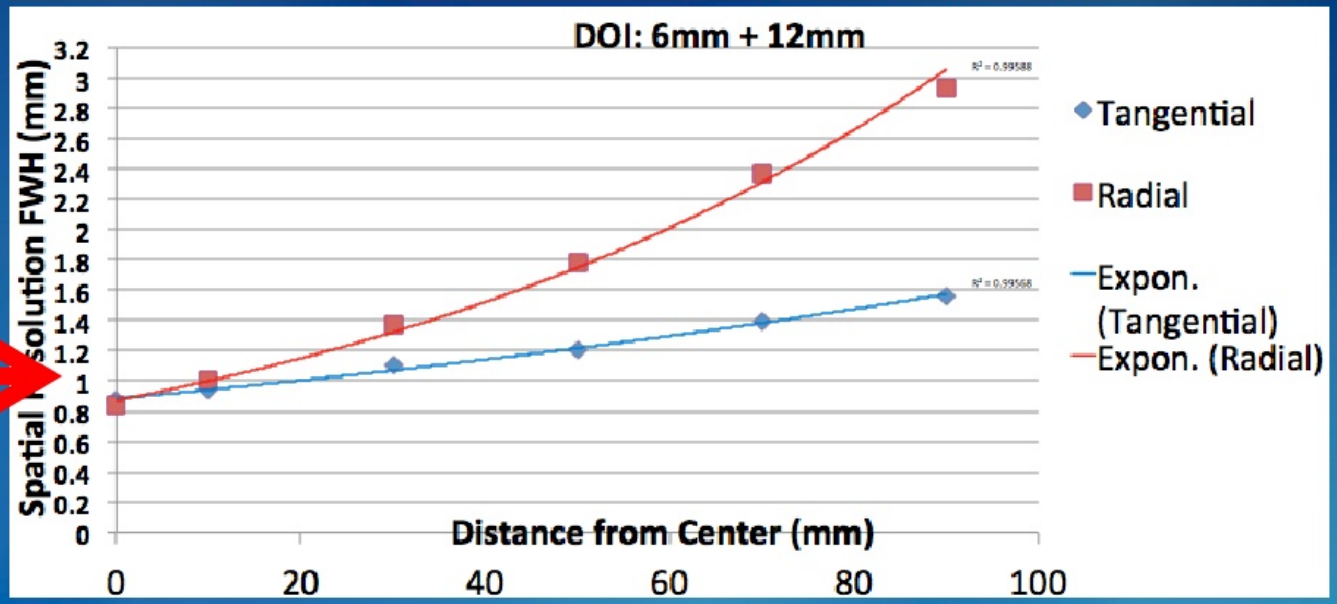
-Simulations show that 1.5mm pitch intrinsic resolution and 6mm DOI resolution result in ~1mm resolution of the reconstructed images in a large fraction of the detection volume of the ~25cm inner diameter PET ring brain imager.

Other factors limiting resolution:

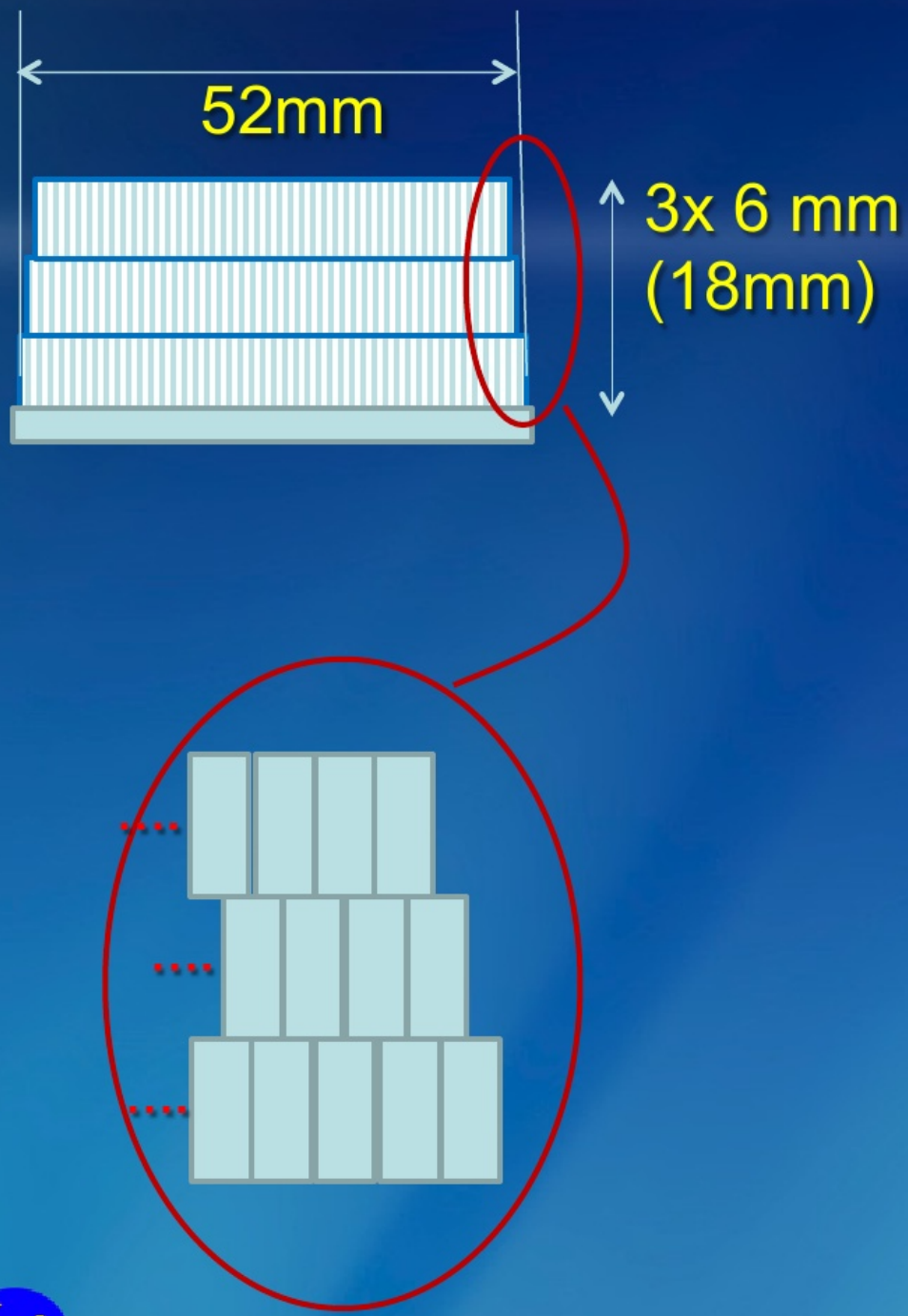
- Positron range
- Non-colinearity of annihilation gammas (less of an issue in the brain imager case due to compact geometry)
- Event statistics (due to radiation intensity (dose, uptake) and scan time) necessary to obtain useful images with high enough S/N and contrast

# Simulation results: resolution plots



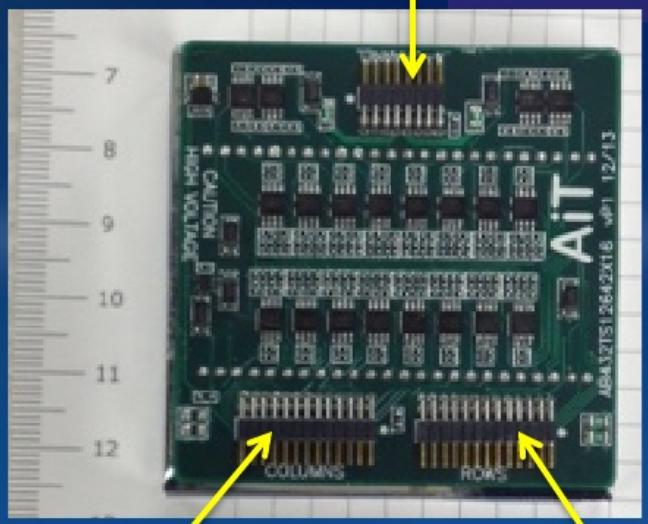

GATE simulation results. FWHM spatial resolution versus distance from the center of a 24 cm PET ring composed of 16 modules ~5cm (wide) x10cm (high) each, with intrinsic pixel resolution of 1.5mm and with two (6mm + 12mm, bottom plot) and three 6mm (top plot) scintillation layers. It is assumed that the layers can be separated and this provides the Depth of Interaction (DOI) measurement. Predicted spatial resolution in the central region is less than 1mm FWHM and increases to ~2 mm at the outer region, in the case of 3x6mm layers.



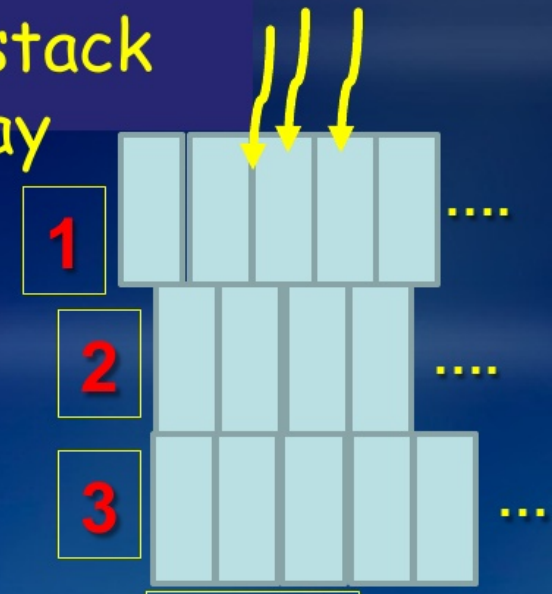

**Approach: 3 pixel layers:**

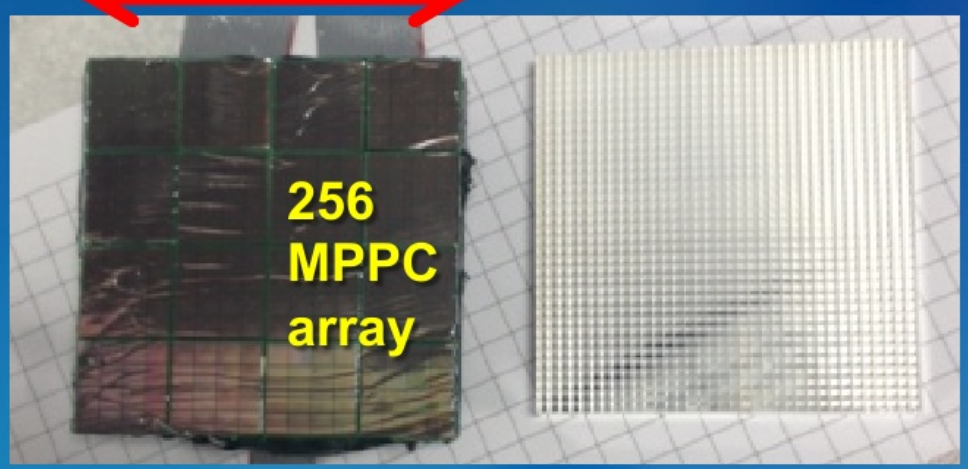
- 1.5 mm pixel size
- 6 mm per layer
- Layers are staggered
- Total thickness: 18mm of LYSO
- Special pixel side surface treatment
- Cooled @ 15 deg. C
- R&C readout
- Truncated COG algorithm

# Studies of the LYSO array stack with the 16x16 MPPC array

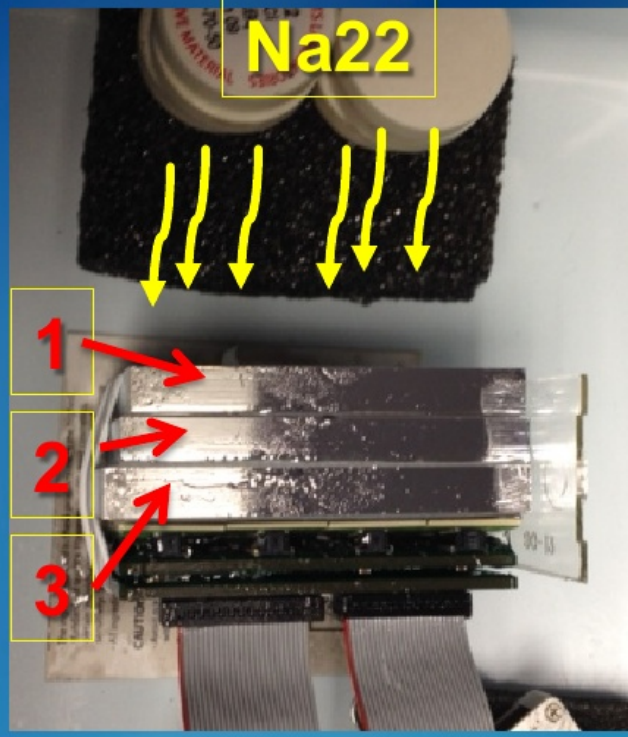



Hybrid readout board from AiT Instruments with the row-and-column outputs and a 4ch output.

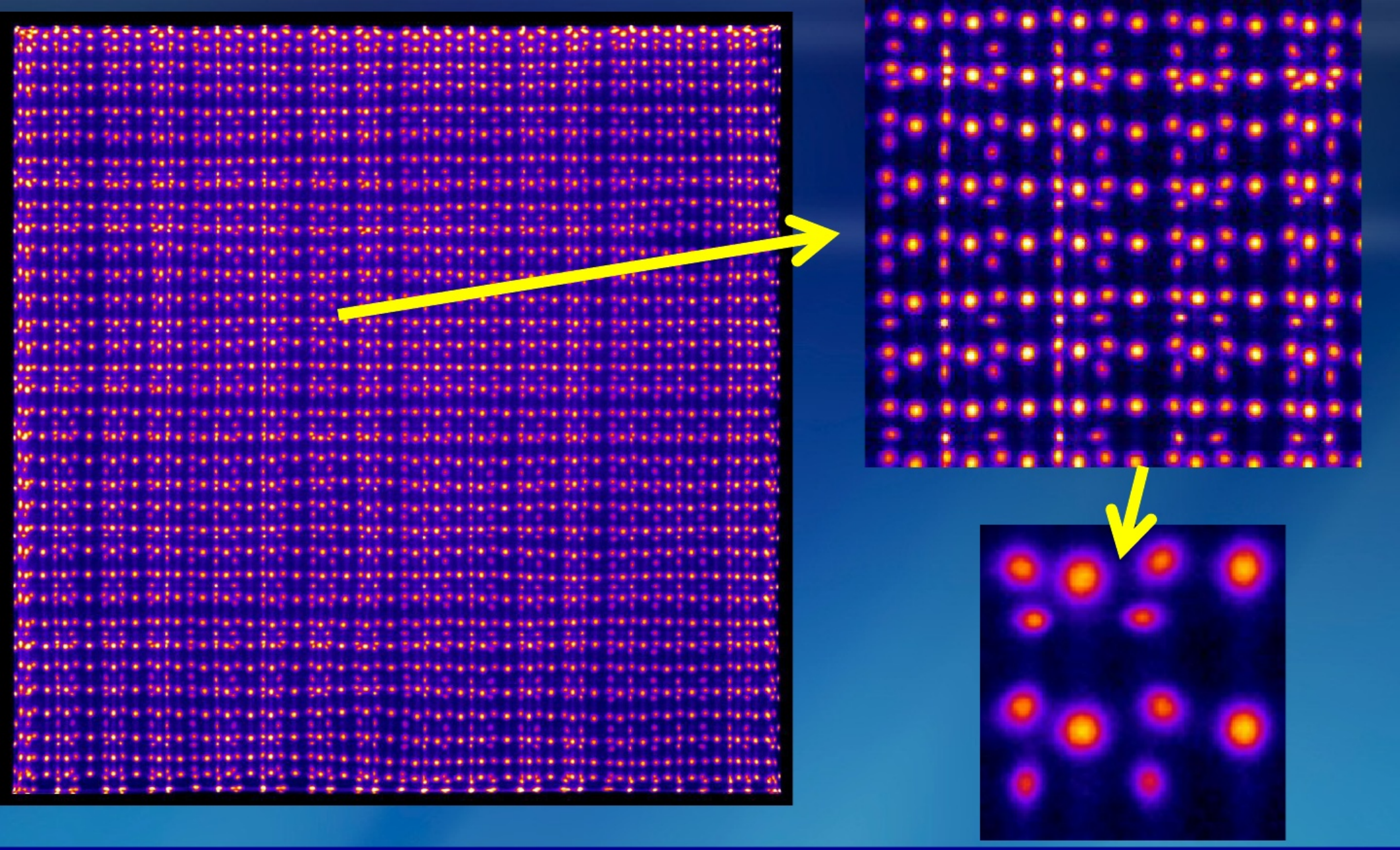


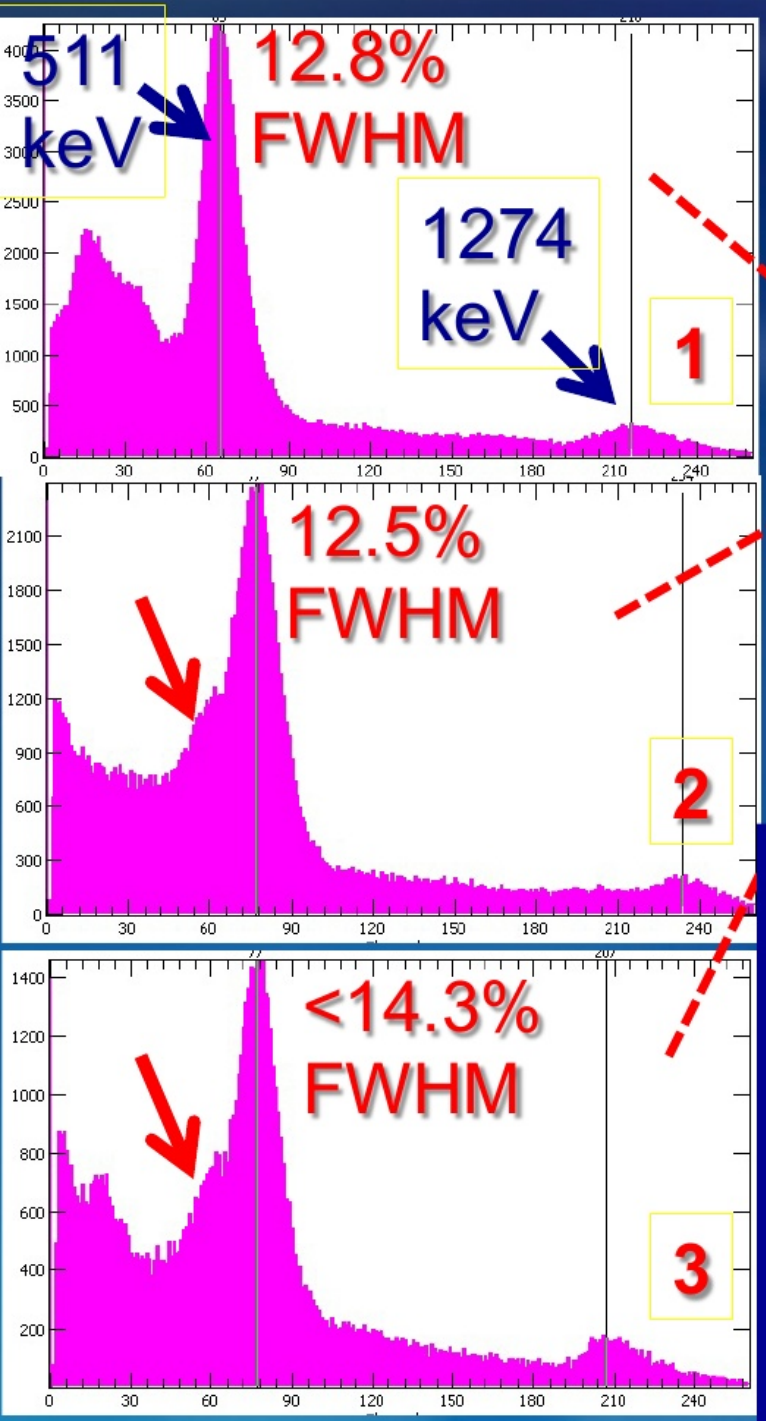

Left: The MPPC array just before being optically coupled to one of the 1.5mm pitch 6 mm thick LYSO pixel arrays from Proteus. The pictured here LYSO array is from the middle of the stack (#2) and has no top reflector.

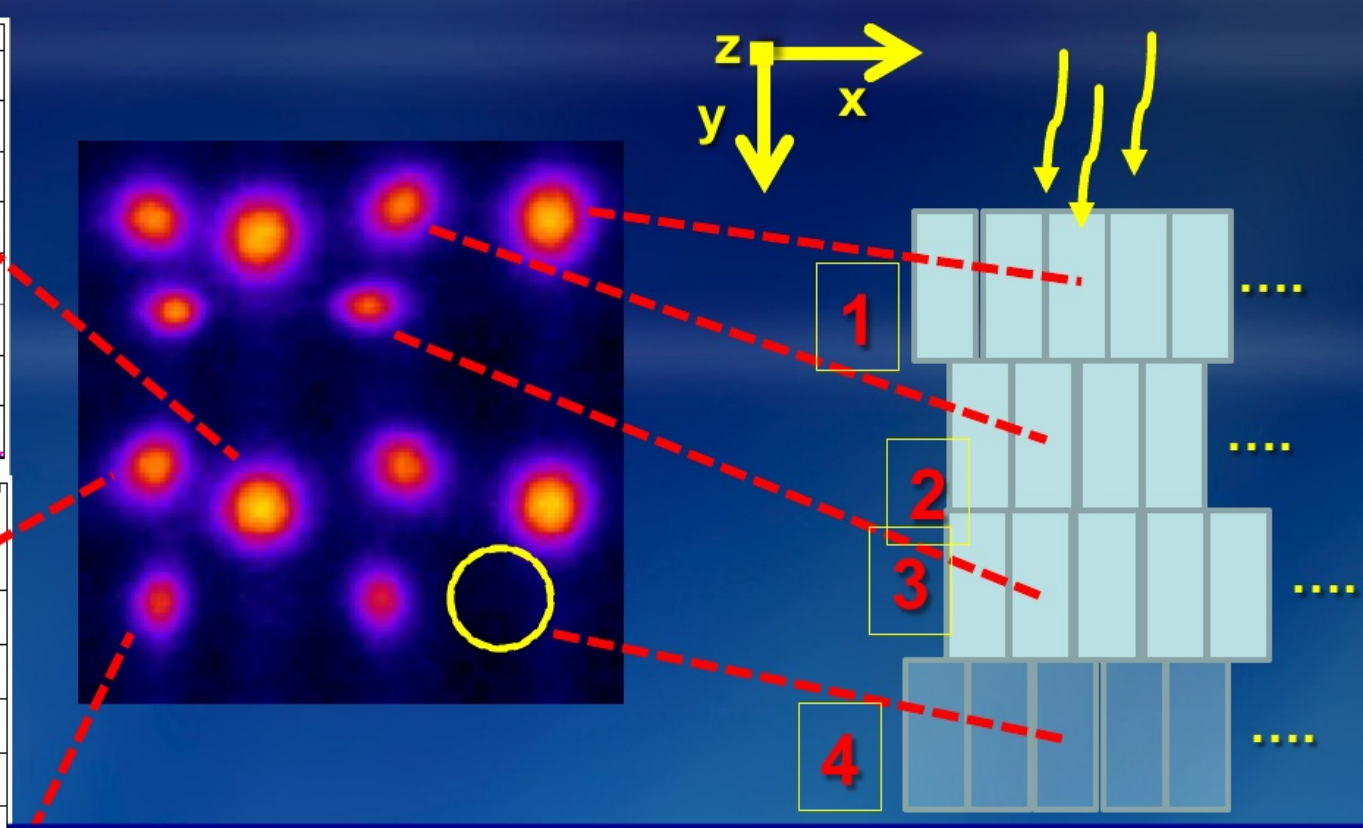



256 element MPPC array was tested with three 1.5mm LYSO arrays from Proteus coupled directly, without an additional optical window, to the MPPC array. Visilox V-788 optical coupling compound was used between the MPPC array and the LYSO arrays.

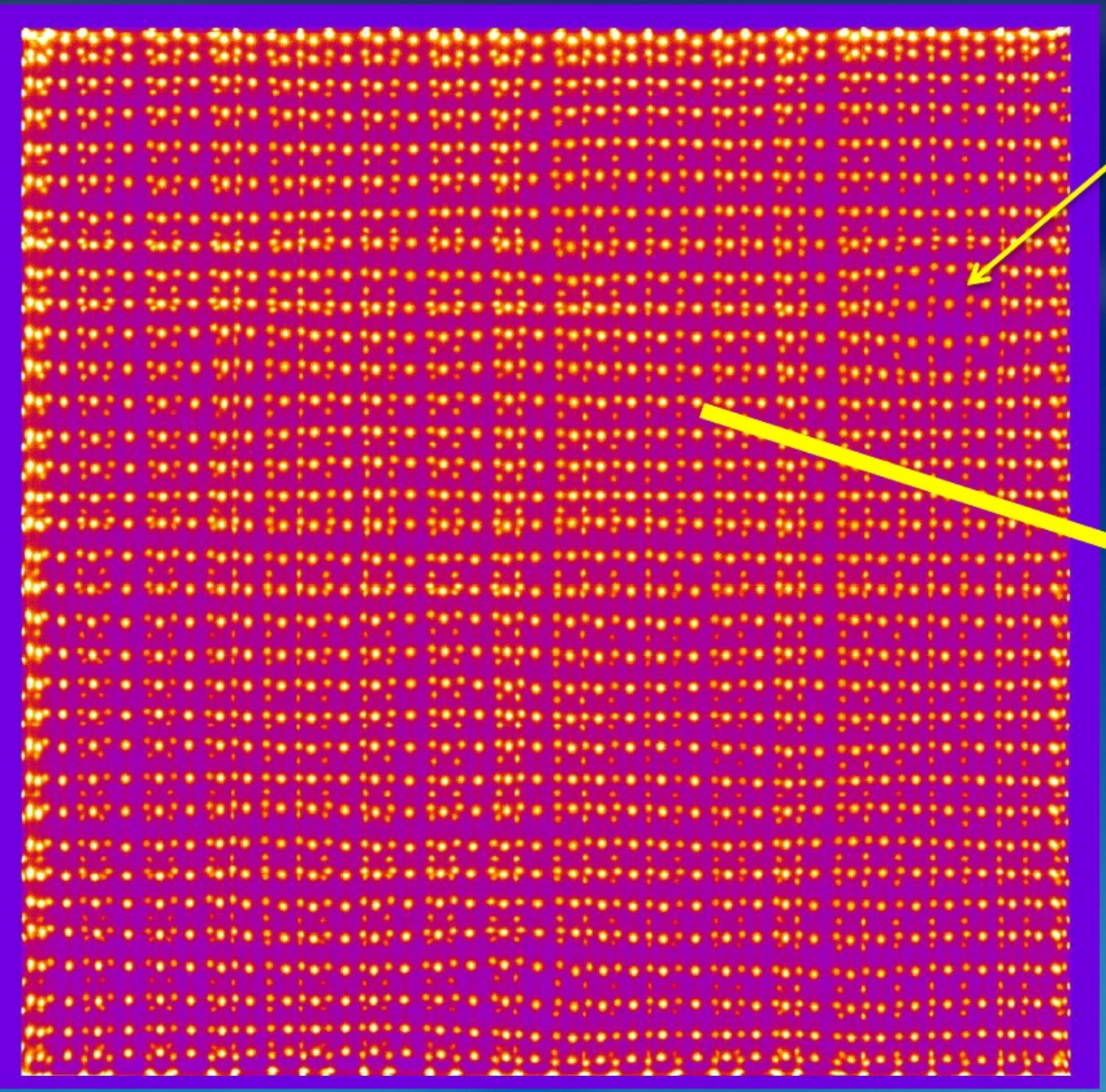


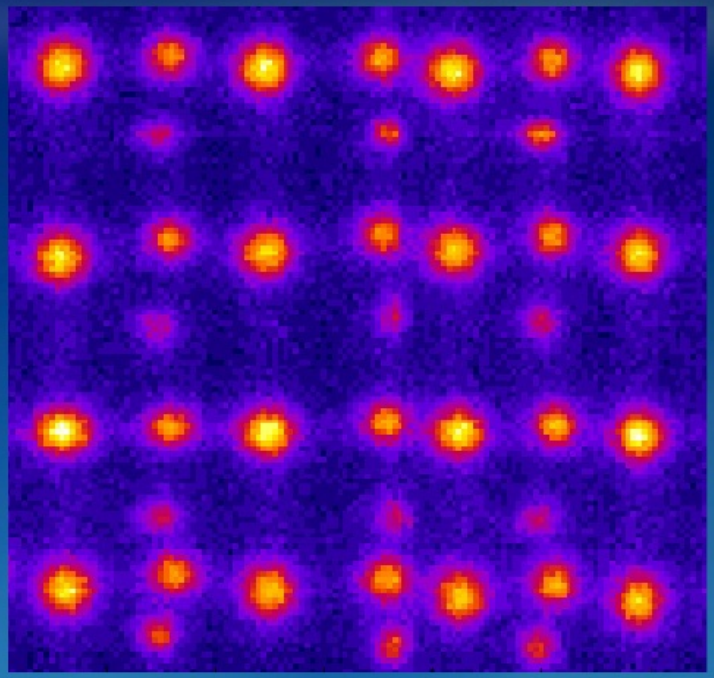
Full-size raw image at left shows that about 3500 LYSO pixels separate well across the full FOV, including the corners. The two-step zoom shows the details of the spatial separation performance.
(Conditions: Bias 66.6 V, Temp 15 deg C, Row-and-Column readout, 170 ns integration gate to ADC, ADC attenuator 2, truncation COG factor 0.025.)



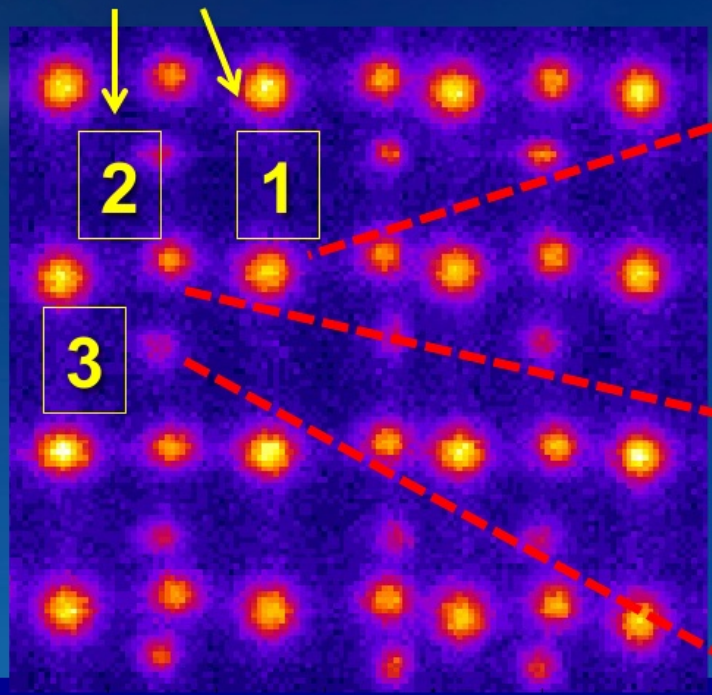

Pixels of the three arrays separate in the raw images. The arrays are shifted relative to each other by $\frac{1}{2}$ of the pixel pitch (1.50mm/2) in the x and z (into the slide) directions. There is room in principle for another array, number four. Three examples of energy spectra for the LYSO pixels are shown. The red arrows indicate peaks in layers 2 and 3 with less than 511 keV energy deposit due to scattered gammas in layer 1. Inclusion of 1274 keV peak from Na22 allows energy zero calibration which is necessary when using the diode-based row-and-column circuit. The energy spectrum at left bottom had 1274 keV peak saturated and the calculated FWHM energy resolution value @511 keV for pixel #3 is an upper limit.

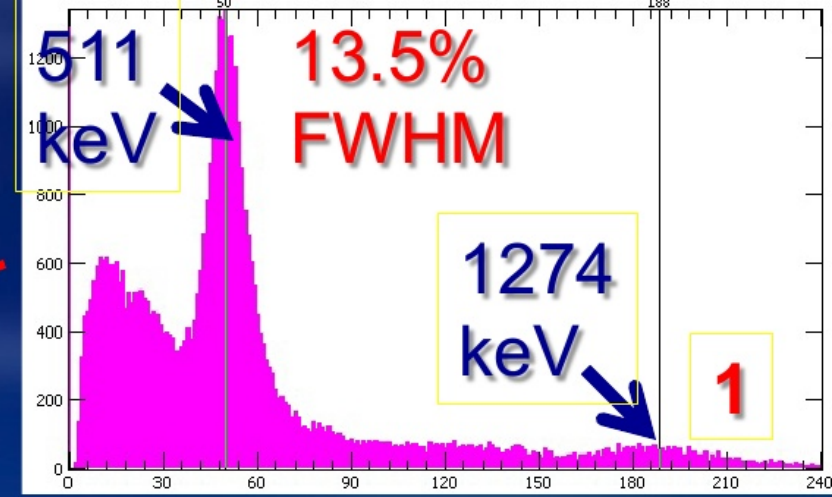


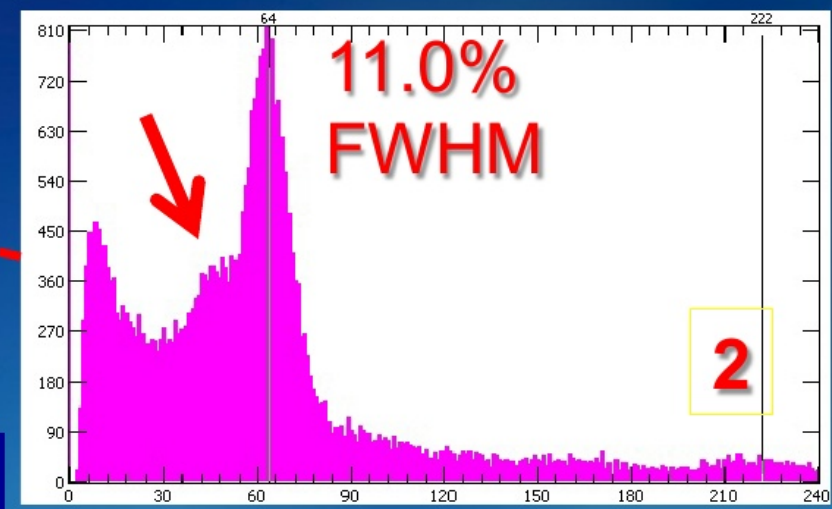



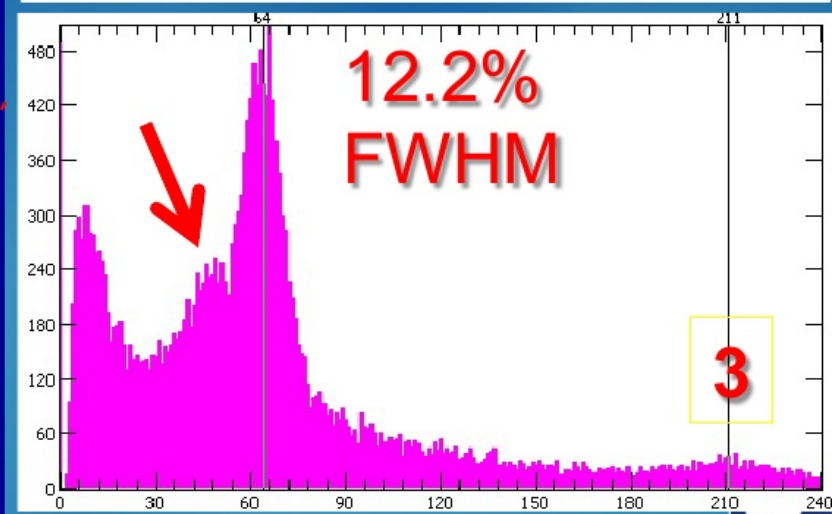
New conditions: Bias 66.6 V, Temp 22 deg C, Row-and-Column readout, 170 ns integration gate to ADC, ADC attenuator 1.0, truncation COG factor 0.025.

LYSO array
layer Number:



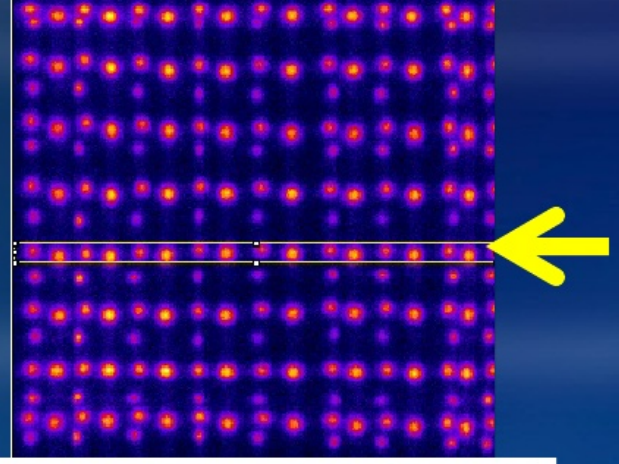



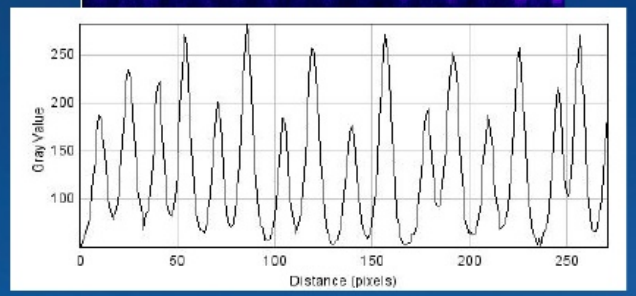



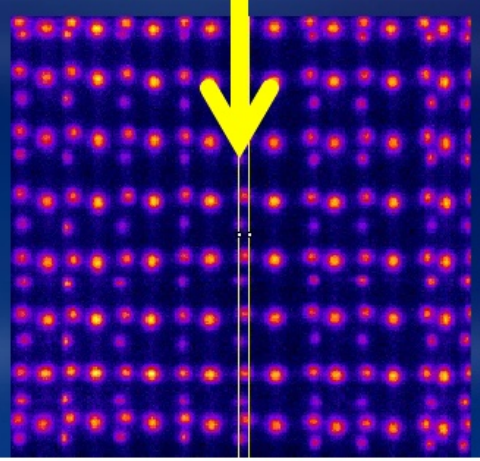



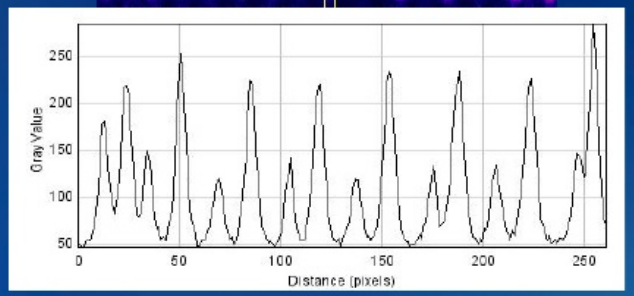

Examples of energy spectra and energy resolution values. The red arrows indicate peaks in layers 2 and 3 with less than 511 keV energy deposit due to scattered gammas in layer 1.
(Conditions: Bias 66.6 V, Temp 22 deg C, Row-and-Column readout, 170 ns integration gate to ADC, ADC attenuator 1.0, truncation COG factor 0.025. In these lower gain (higher temperature) conditions the correction for zero energy channel was even more important. The zero energy shift is due to AiT diode circuitry used in lieu of the standard resistor network. )

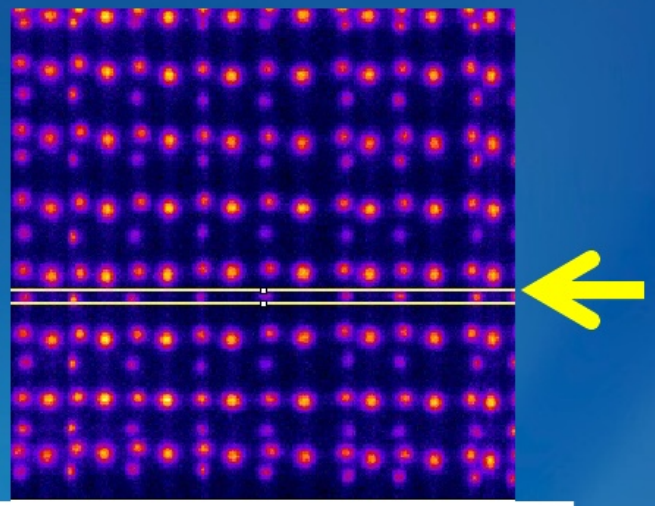
Several examples of profiles through the pixel "dots". The separation in 2D is stronger than in any of the projections.

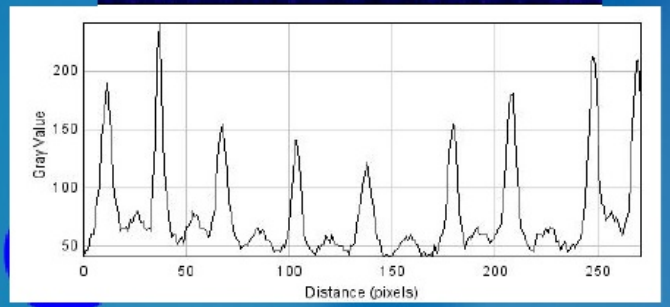


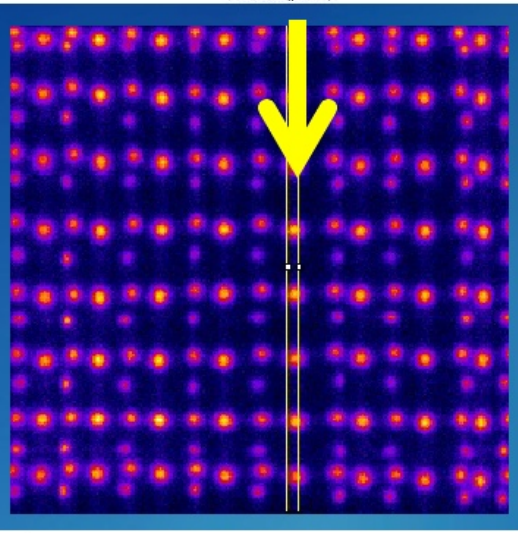


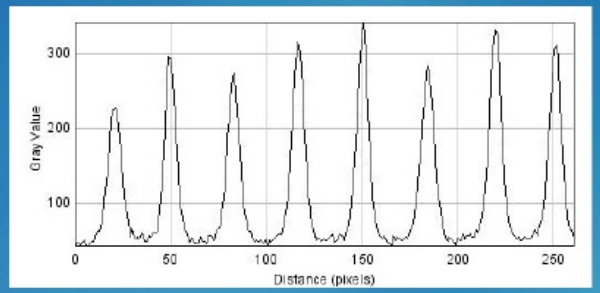



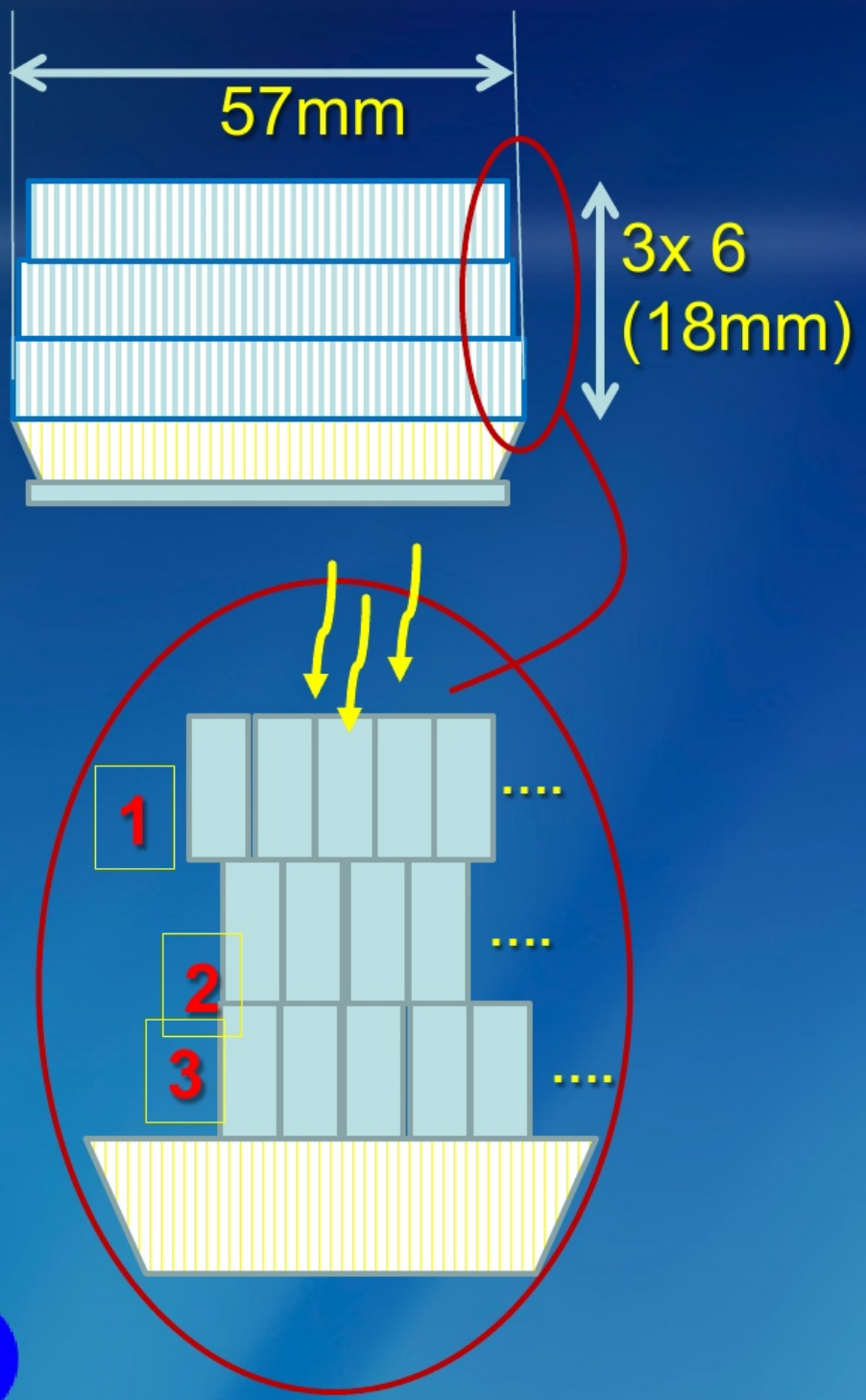




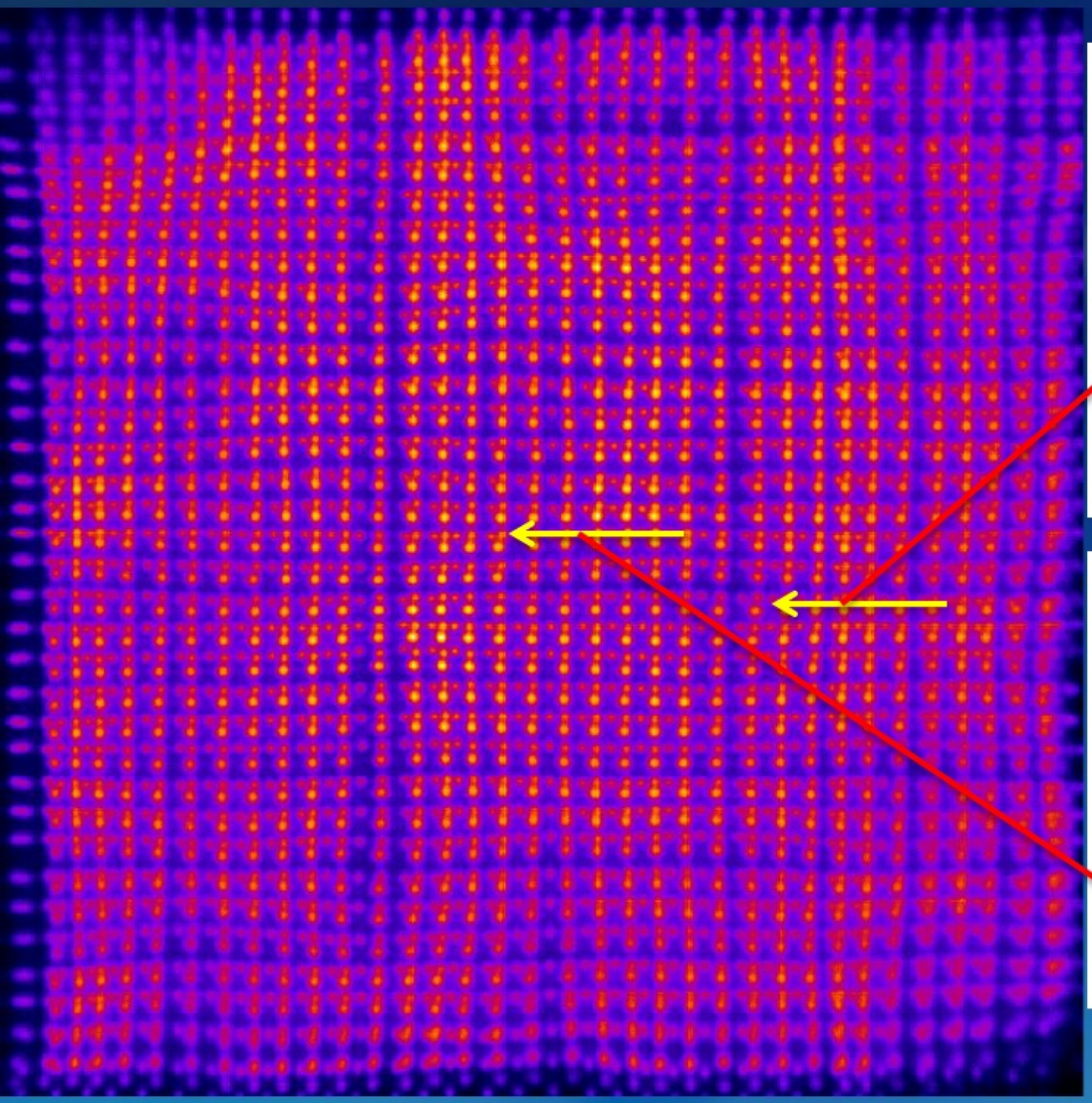



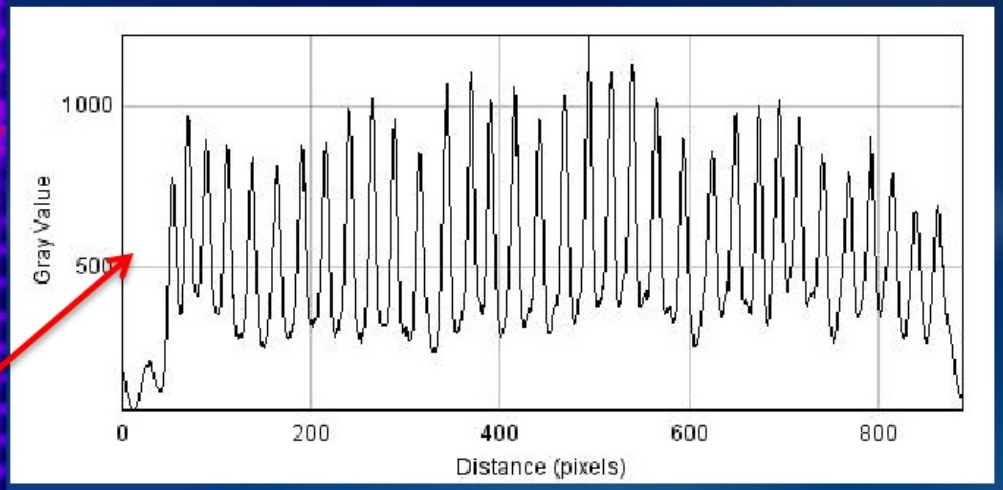


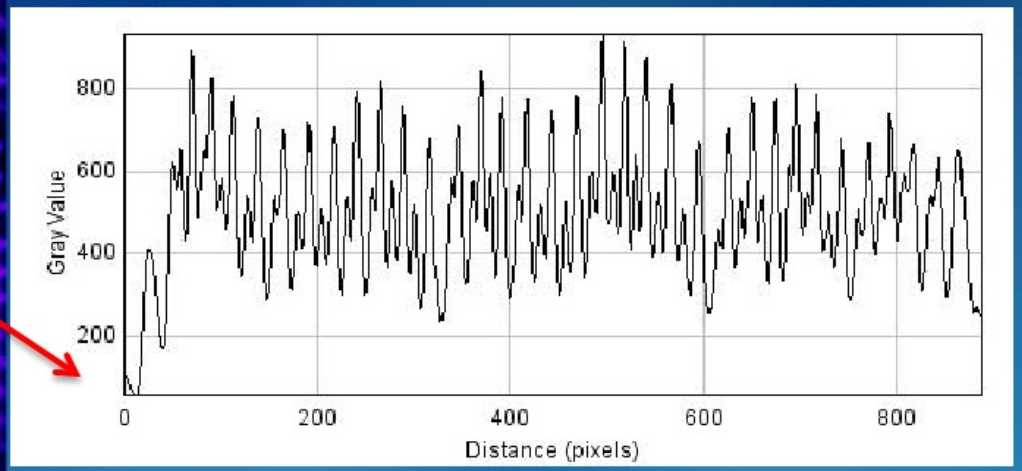



**Approach: 3 pixel layers plus tapered light guide:**

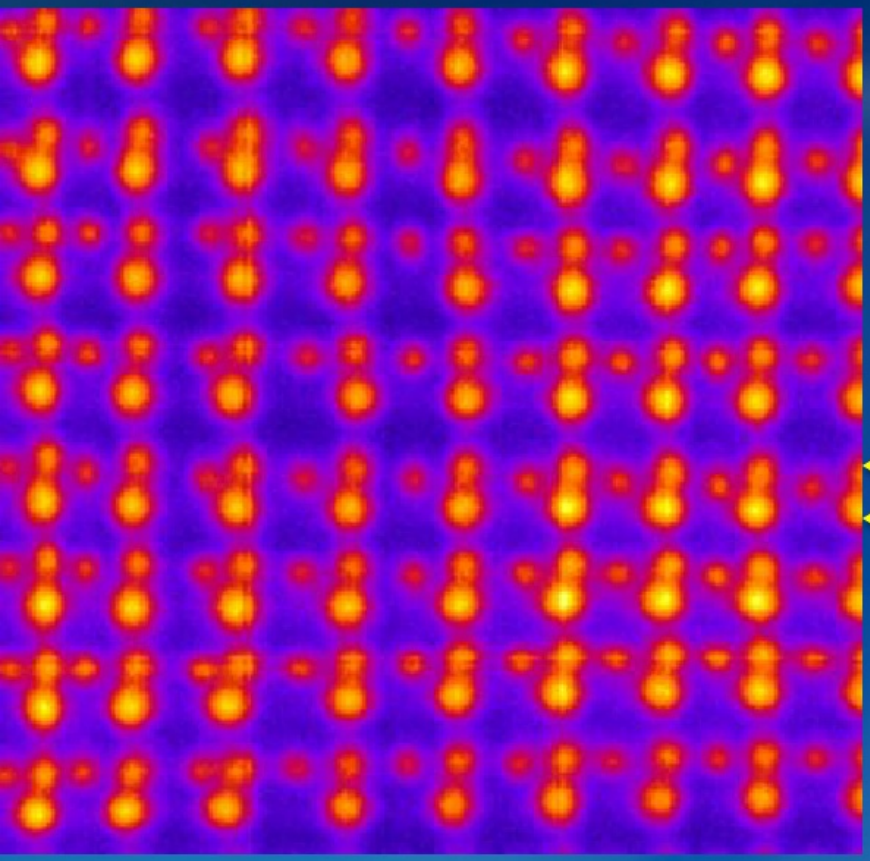
- 1.5 mm pixel size
- 6 mm per layer
- Layers are staggered
- Total thickness: 18mm of LYSO
- Special pixel side surface treatment
- Cooled @ 15 deg. C
- R&C readout
- Truncated COG algorithm

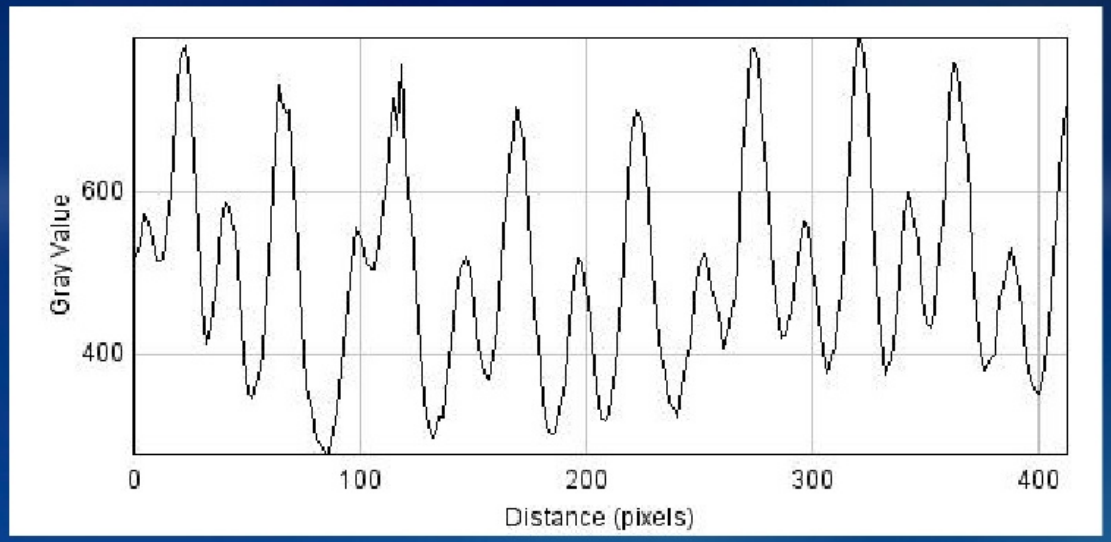


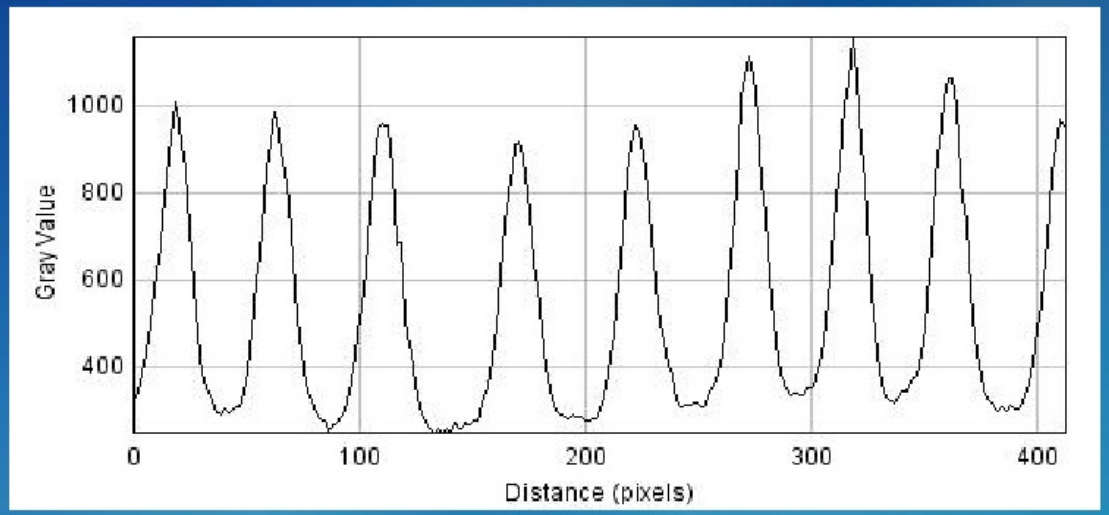


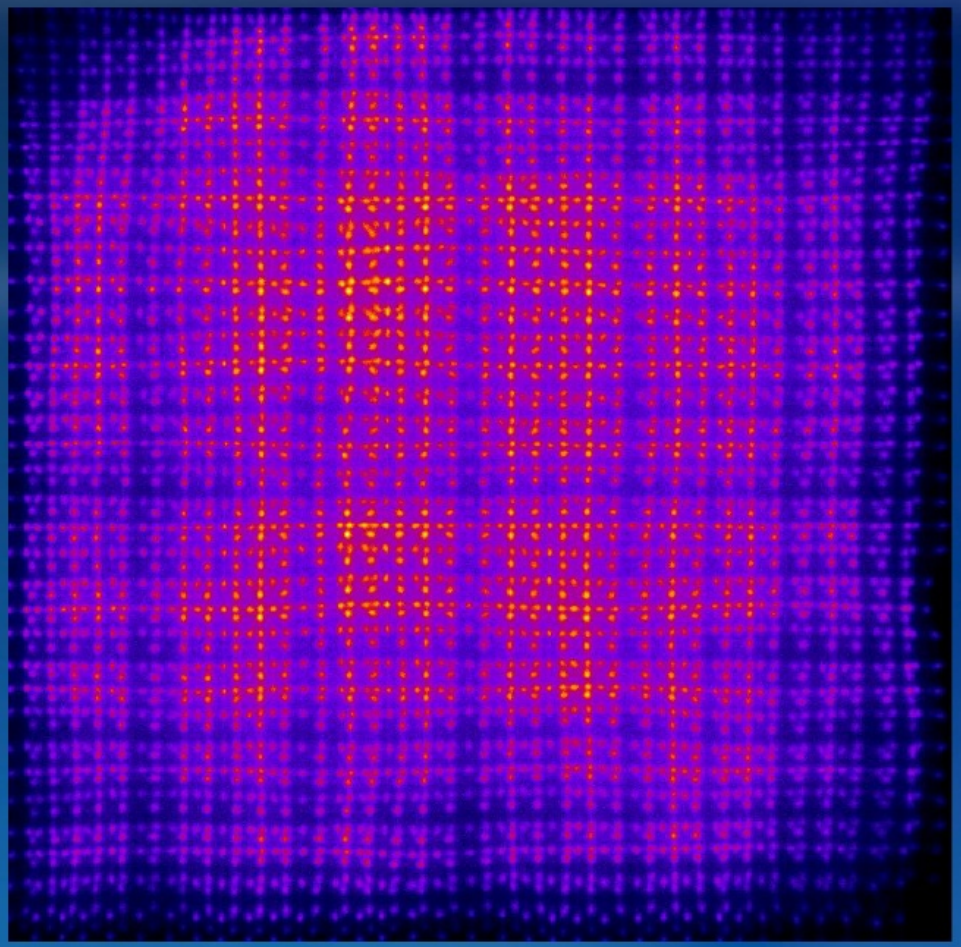

Raw image and two plots at 511 keV. (Conditions: Bias 66.2 V, Temp 15 deg C, Row-and-Column readout, 170 ns integration gate to ADC, ADC attenuator 1.0, AC coupling of the signal to ADC. Truncation COG factor 0.025).

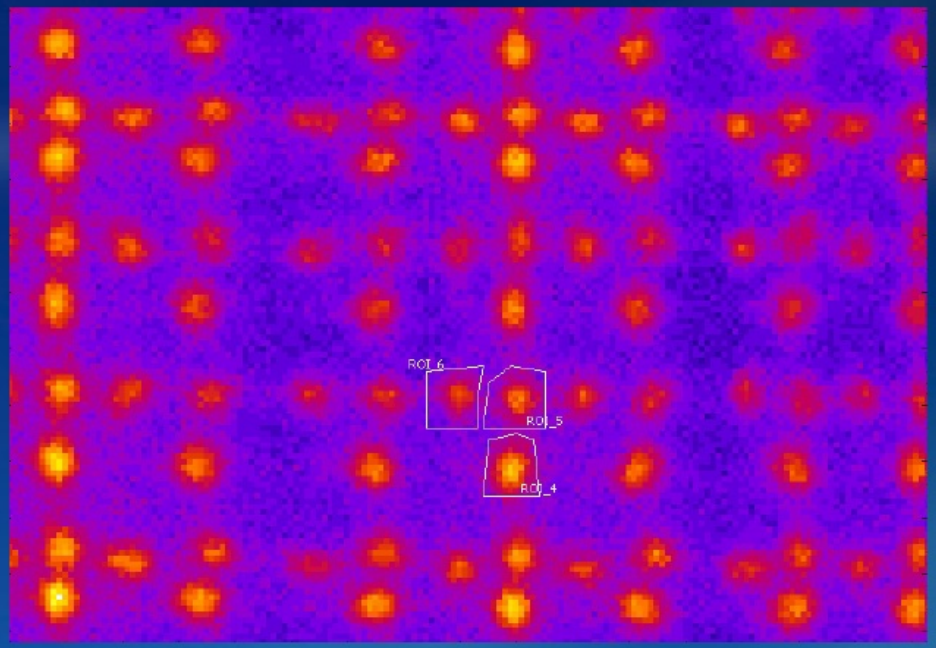




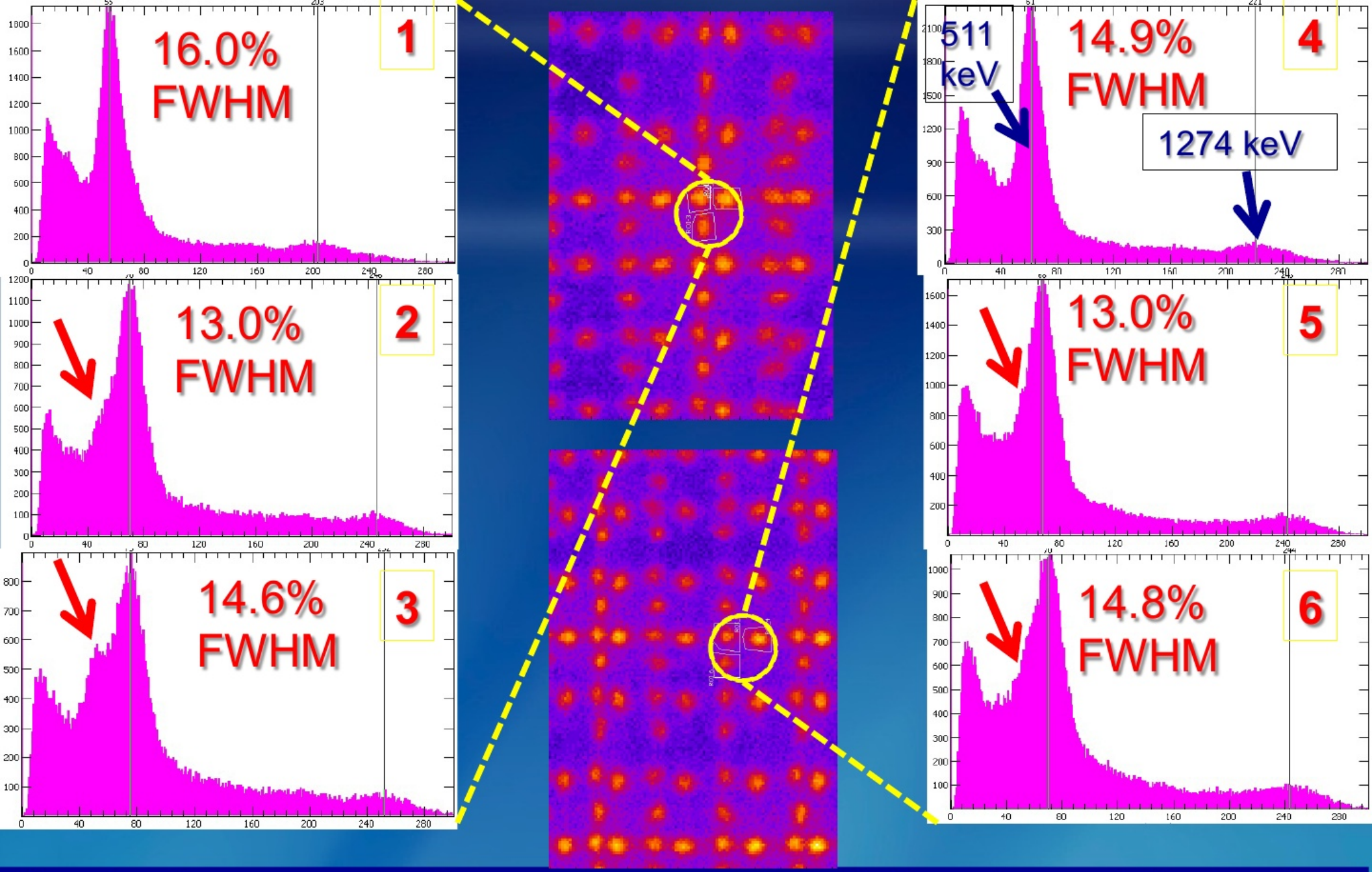




Zoom of the raw image and two plots at 511 keV. (Conditions: Bias 66.2 V, Temp 15 deg C, Row-and-Column readout, 170 ns integration gate to ADC, ADC attenuator 1.0, AC coupling of the signal to ADC. Truncation COG factor 0.025).

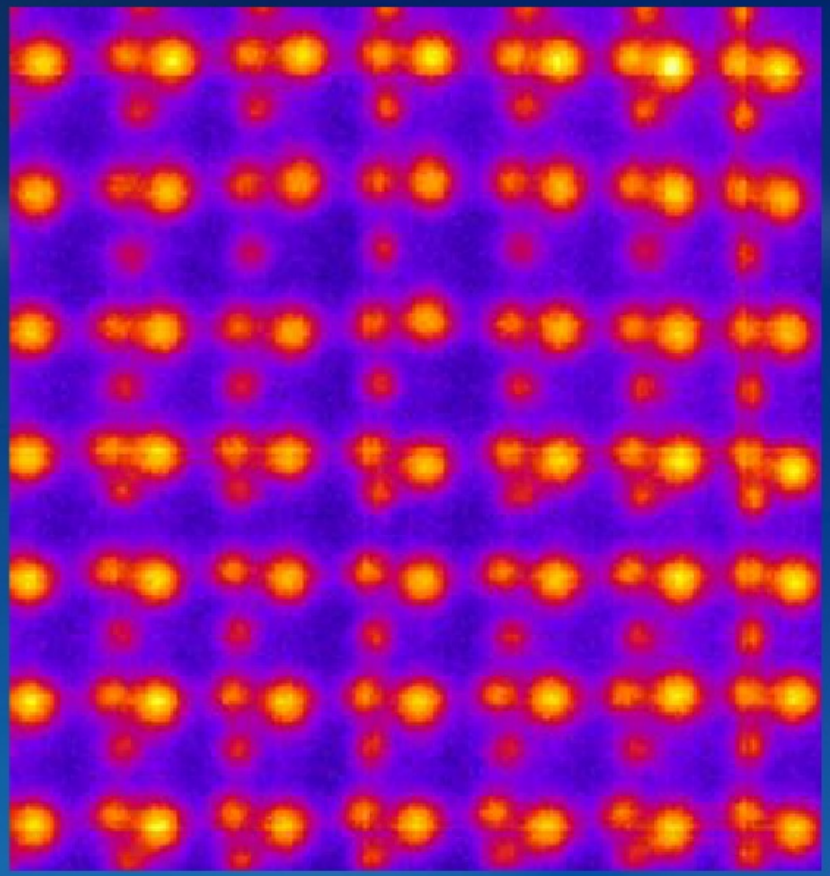




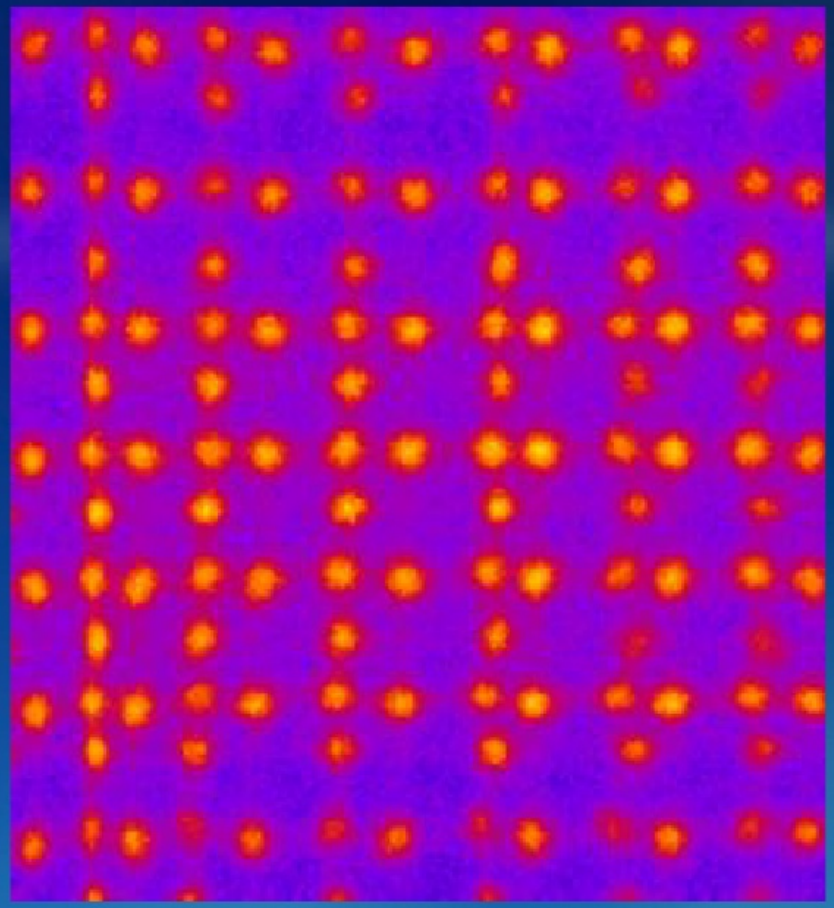

Raw image at 1274 keV can be used to assist with separation of the pixels that are marginally separated in the 511 keV image. (Conditions: Bias 66.2 V, Temp 15 deg C, Row-and-Column readout, 170 ns integration gate to ADC, ADC attenuator 1.0, AC coupling of the signal to ADC. Truncation COG factor 0.025).




Examples of energy spectra. Zoom raw images at 1274 keV. The red arrows indicate peaks in layers 2 and 3 with less than 511 keV energy deposit due to scattered gammas in layer 1. (Conditions: Bias 66.2 V, Temp 15 deg C, Row-and-Column readout, 170 ns integration gate to ADC, ADC attenuator 1.0, AC coupling of the signal to ADC. Truncation COG factor 0.025).

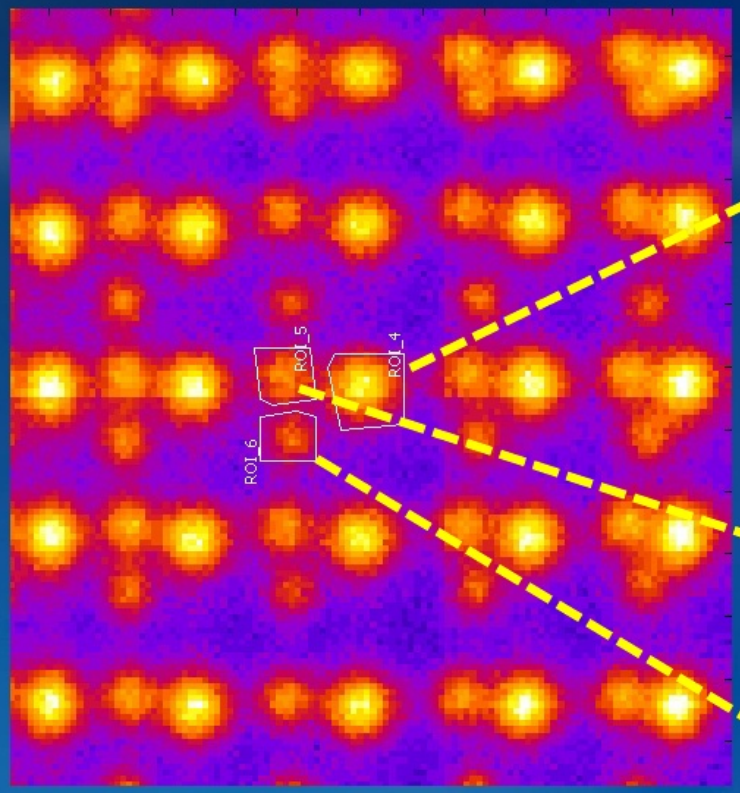


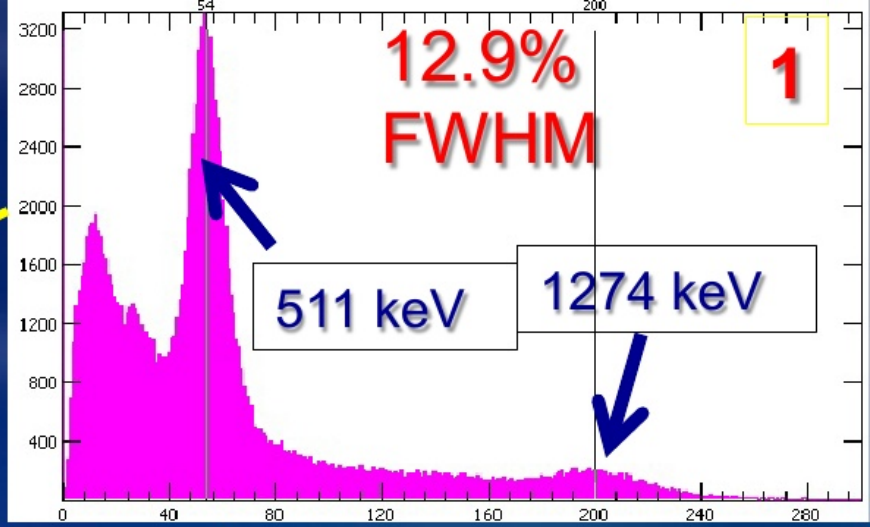
511 keV

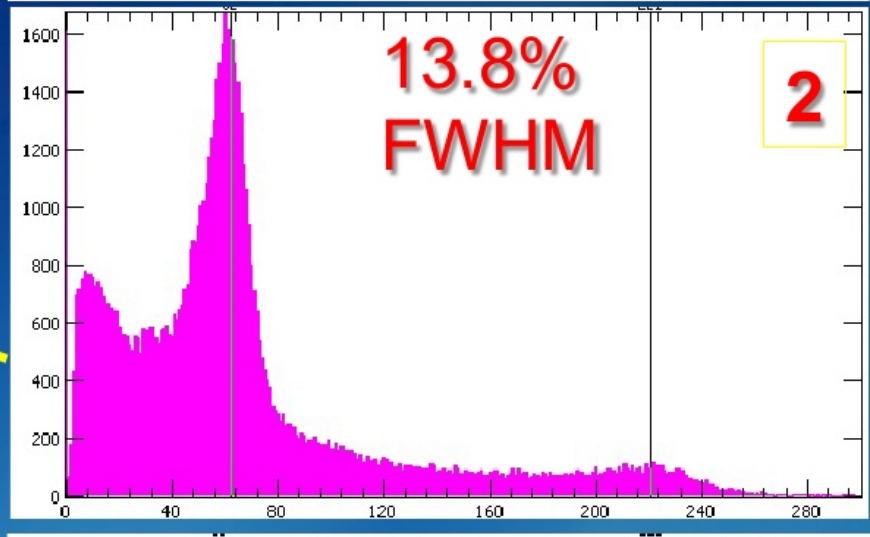


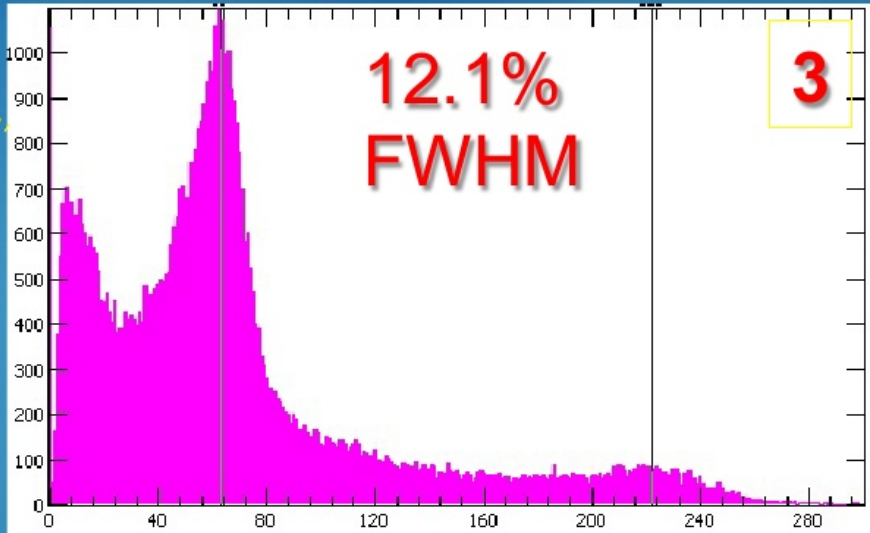
1274 keV

Raw images at 511 keV and 1274 keV. Pixels separate better in the 1274 keV image that can be used as a better guiding map. (Conditions: Bias 66.9 V, Temp 22 deg C, Row-and-Column readout, 170 ns integration gate to ADC, ADC attenuator 1.0, AC coupling of the signal to ADC. Truncation COG factor 0.025).

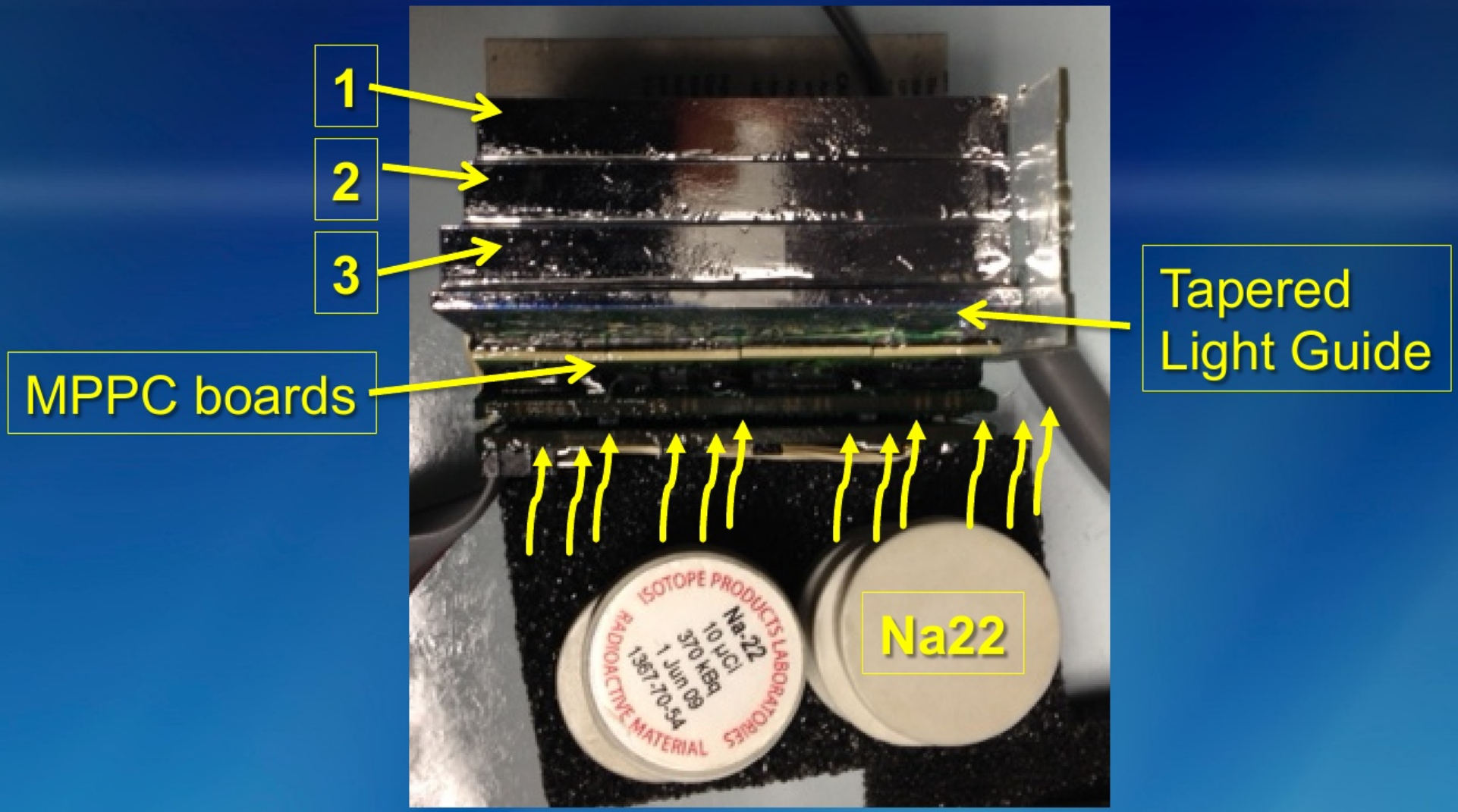


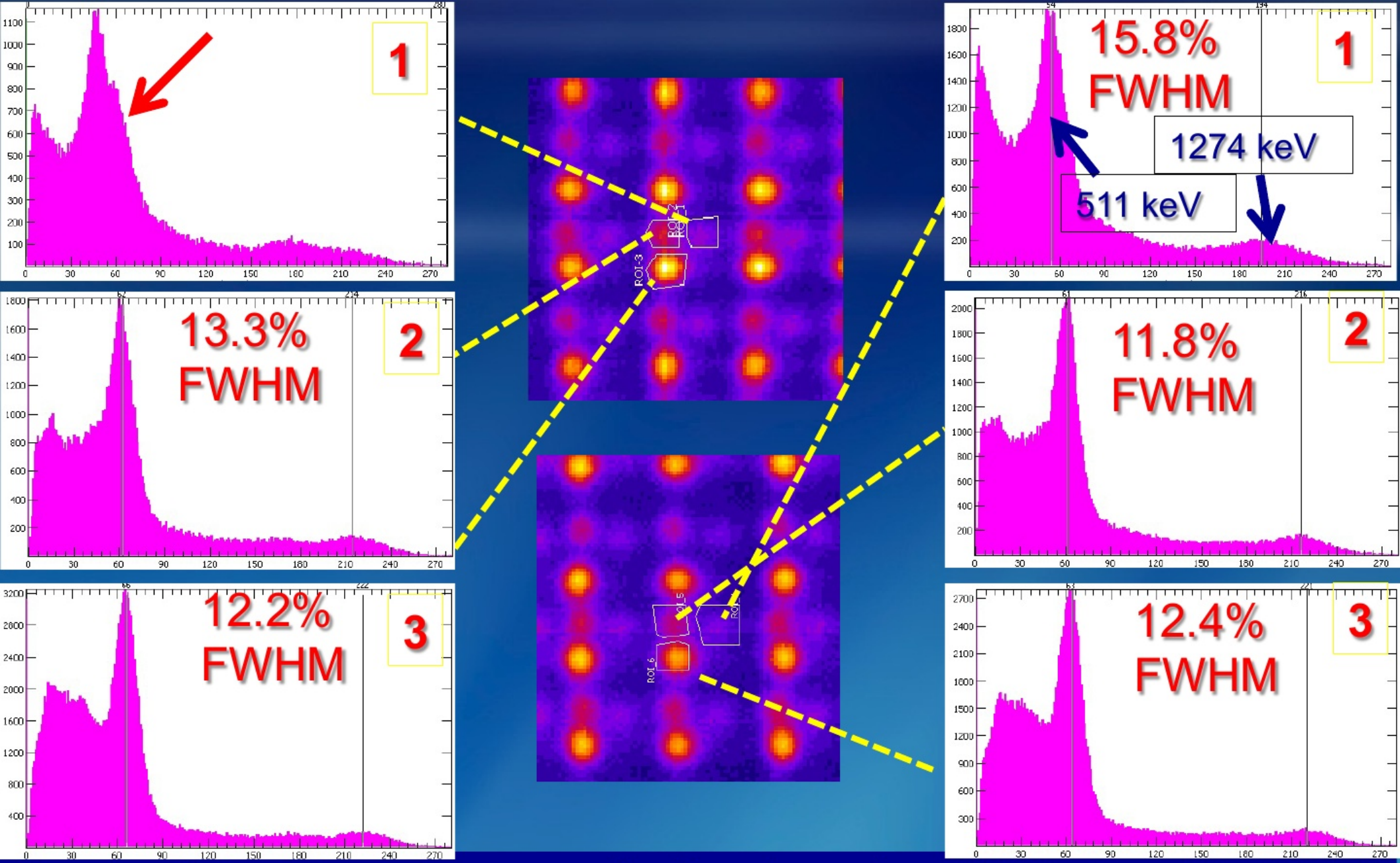




Examples of pixel energy spectra: one pixel at each layer, marked 1-3. (Conditions: Bias 66.9 V, Temp 22 deg C, Row-and-Column readout, 170 ns integration gate to ADC, ADC attenuator 1.0, AC coupling of the signal to ADC. Truncation COG factor 0.025).




Irradiation of the scintillator stack from the back - SiPM side - to invert the intensity ratios of the signals coming from the three LYSO arrays in the stack.




Examples of six single pixel energy spectra from two regions. FWHM values at the 511 keV photopeak are shown, except one pixel where scatter peak broadened the peak. As before, 1-3 are three scintillator array layers, starting from top (1) to bottom (3) of the stack. (Conditions: Bias 66.9 V, Temp 22 deg C, Row-and-Column readout, 170 ns integration gate to ADC, ADC attenuator 1.0, AC coupling of the signal to ADC. Truncation COG factor 0.025).

# Summary of the pilot LYSO array stack studies coupled to the latest generation of 256 MPPC array

- All three LYSO arrays are well separated across the surface of the whole detector module with the row-and-column (R&C) readout, when used without the tapered light guide
- There is a potential for adding a fourth layer
- Energy resolution is under 15% FWHM @ 511 keV for all the layers
- Moderate cooling (15 deg C down from 22 deg C) does not improve visibly the performance but helps to stabilize the gain of the MPPC array (gain is temperature-sensitive)
- Adding tapered light guide decreases performance but the pixels can be still separated and energy resolution is around or lower than 15% ; this configuration needs more optimization – also a potential redesign of the light guide
- In summary, the initial goals set for the PET module performance were achieved